P2.13 Examination of Thundersnow Cases in the United States Utilizing NLDN Data

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1. Introduction

Cloud to ground (CG) lightning strikes recorded by the National Lightning Detection Network (NLDN) are used in examining case studies of thundersnow from the 2003-2004 winter season across the central United States. While often times the electrical discharge will be in-cloud with cold season, elevated convection, NLDN data provide valuable supplemental information to the traditional surface reports in exceptional cases. In particular, more precise temporal and spatial specifications for the thunderstorm can be achieved. For this purpose, a composite plot with observations from surface stations was performed in each archived event.

The thermal characteristics for the associated convection were then identified by noting whether the lightning strike occurred with surface temperatures above, at, or below freezing. As a result, this information helped to substantiate the true existence of thundersnow, and thus, better define the true initiation time. Finally, the polarity of each lightning strike is recorded, thereby providing information on the electrical nature of these storms.

Preliminary analysis revealed CG lightning strikes occurred in only seven of the fourteen original thundersnow case studies. This does not discount the validity of the seven thundersnow case studies in which CG lightning did not occur since in-cloud lightning may have been occurring. It does however offer solid evidence that a thundersnow event has occurred within these seven confirmed cases. Further study of the seven cases involving CG lightning strikes will be performed including analysis of surface temperature and CG strike count.

2. Methodology

CG lightning data for this study was obtained from the NLDN, which records CG strikes across the United States continuously and disseminates the data every five minutes. Operationally these data are invaluable when used in conjunction with radar and satellite observations. NLDN is capable of detecting cloud to cloud lightning strikes but at this point such data are unavailable.

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The inability to document in-cloud lightning discharges is a significant problem for this study since in order for an event to be substantiated, evidence of lightning activity must be documented.

Composite surface analyses were performed on each of the seven confirmed CG thundersnow cases. Composite surface maps comprised of CG lightning strikes plotted against surface observations were constructed to provide a spatial representation of where CG strikes occurred and what surface temperature regimes the individual strikes occurred in (refer to Fig. 1). Furthermore, only CG strikes occurring in the vicinity of surface stations reporting snowfall and at temperatures below 36°F were recorded in this analysis. By meeting these criteria it is assured that the CG strike is associated with a thundersnow event and did not occur in the warm sector of the system.

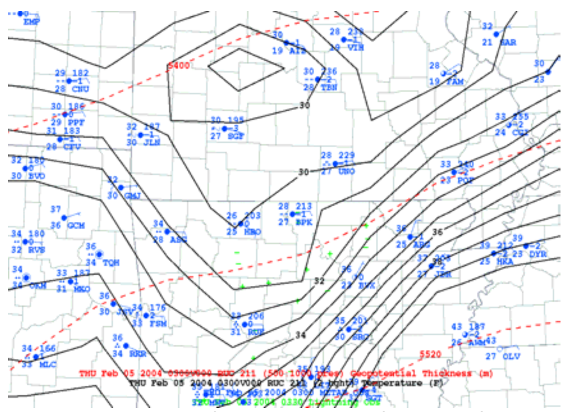

Figure 1. Example of a composite surface map featuring NLDN data, surface observations, and overlaid with RUC surface isotherms (solid black; every 2F) and 1000-500hpa thickness (dashed red; every 60gpm). Analysis valid at 0300 UTC 05 February 2004, with lightning valid 0330 UTC.

After each thundersnow case was evaluated, a statistical analysis was performed on the seasonal total count of CG strikes with respect to surface temperature. Various statistical techniques such as Pearson's correlations were implemented to establish that a relationship exists between CG activity and surface temperature.

Additionally a relationship between cloud top temperature and CG thundersnow events will be investigated. Composite maps incorporating NLDN data are overlaid with GOES 12 infrared imagery (refer to Fig. 2) and the associated cloud top temperature recorded at the location of every CG strike.

Unfortunately only hourly GOES 12 data were available for this study. This required both that some assumptions be made and certain temporal limits be set. It must be assumed that the cloud top temperature did not change much over a thirty minute period. With this assumption set; only CG strikes occurring fifteen minutes prior to the top of the hour and fifteen minutes after the top of the hour were recorded. Although this method falls short of recording the exact cloud top temperature at the time of each individual lightning strike a general idea of the cloud top environment can be obtained through this method of investigation.

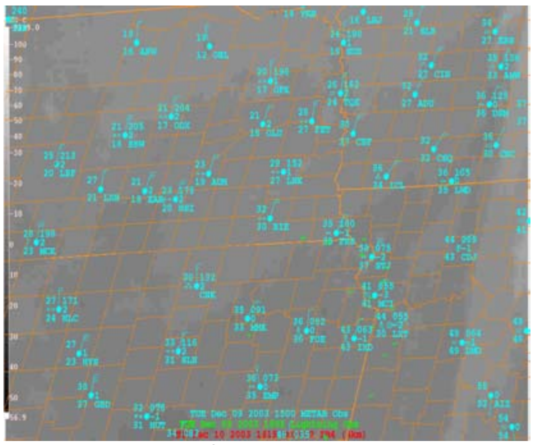

Figure 2 Example of a composite IR satellite image featuring NLDN data and surface observations. Surface observations valid at 1500 UTC 09 December 2003, 1505 UTC lightning observations and 1505 GOES 12 IR image.

3. Surface Temperature Analyses

Of the fourteen thundersnow case studies only seven exhibited CG lightning strikes. Several features specific to these seven cases were noted. First the rain-snow line, assumed to be the 540dm thickness contour, was in the vicinity of each of the seven thundersnow events. This corresponds to the fact that these seven cases occurred primarily in a surface environment in which the temperature fell between 36˚F to just below freezing, 32˚F. The lowest surface temperature recorded in this study was 26˚F at which only nine CG strikes occurred. These strikes were primarily negative with only one positive strike occurring during this event. Additionally no CG lightning strikes were recorded at surface temperatures below 26˚F.

During an investigation of CG activity occurring below 32˚F Moore and Idone (1999) noted an increase of CG activity as a function of surface temperature. Similar evidence was found in this study; as surface temperature increased so did CG lightning activity (Fig. 3). Recall that in order to insure that we are only dealing with CG activity associated with snow events only CG strikes associated with surface temperatures below 36˚F and in the vicinity of surface stations reporting frozen precipitation were recorded. Because of this approach, an artificial drop in CG activity is identified in Fig. 3. CG activity actually continued to increase in surface environments above 36˚F. A Pearson correlation was performed on the data set which revealed a solid correlation between increasing surface temperature and increasing CG lightning activity. The resultant correlation coefficient of 0.796 suggests strong correlation between the two data sets.

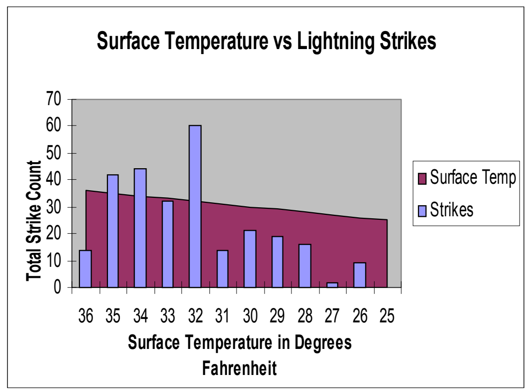

Figure. 3. Surface temperature versus total lightning strike count.

Average observed surface temperature for these thundersnow events was 30˚F. However, the mode value for CG activity occurred at a surface temperature of 32˚F with nearly twenty-two percent of the strikes occurring at this temperature. Only twenty-nine percent of the observed CG strikes occurred at temperatures below the mode value of 32˚F with negative charges greatly outnumbering positive charges. Nearly seventy percent of the 273 recorded CG strikes were of negative polarity. Only eighty-three positive CG strikes were observed in the seven cases suggesting that preferred polarity of CG activity in thundersnow events is negative.

Interestingly negative strikes at temperatures below 30˚F out numbered positive CG strikes by a value of up to eight times greater. An increase in positive CG activity was noted at temperatures above 30˚F. Beyond 30˚F positively charged CG strikes averaged fifty percent of the value of negatively charged CG strikes per given temperature regime.

In order to better demonstrate this phenomenon, both positive and negative CG strikes were plotted against surface temperature. In addition, trend lines were fit to the data set (Fig. 4). Fig. 4 reveals that negative CG lightning activity increased linearly with respect to surface temperature. Meanwhile positive CG activity also increased with rising surface temperature, exhibiting an exponential increase of activity at temperatures between 26˚F and 34˚F. After an inspection of total CG activity beyond 36˚F it is expected that positive CG activity will begin to increase at a linear rate, similar to the rate of increase found in negative CG activity.

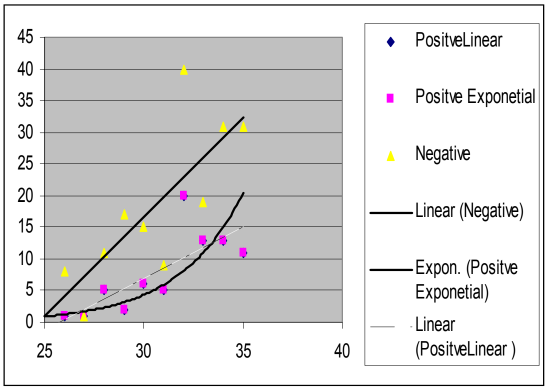

Figure 4. Scatter diagram of lightning strike count versus surface temperature.

Independent Pearson's Correlations were performed on both positive and negative CG strike data sets as a function of surface temperature. Both positive and negative CG values correspond well with the increasing surface temperature. Negative strikes correlated well in relation to increasing surface temperature displaying a resultant correlation coefficient value of 0.778, while positive CG correlated equally well with increasing surface temperature displaying a similar resultant correlation coefficient of 0.777. This analysis matches well with the general findings of Moore and Idone (1999). However, that positive (negative) CG strike counts increase exponentially (linearly) with surface temperature represents a departure from their findings. This is a point that will be examined further as more case studies are completed.

4. Cloud Top Temperature Analyses

Following Beckman (1986), cloud top temperatures were examined to determine repeatable patterns. Cloud top temperatures documented for the seven thundersnow cases averaged -45°C. Clearly these events exhibit characteristic cloud top temperatures of low-top convection. Yet cloud top temperature ranged from -20°C to -69°C. This variation is due in part to the various types of storm systems that support thundersnow events. For instance convective banding was documented in the 23 November 2003 event occurring at Salina, Kansas. Most of the lightning occurring with this event was ahead of the band and the average cloud top temperature was -32°C. In contrast the late season event occurring on 05 March 2004 in Eau, Claire Wisconsin was associated with a warm front in which cloud top temperatures of -42°C were recorded with coldest cloud tops -55°C.

Unlike the correlation found linking surface temperature and CG lightning, no substantial correlation was found relating cloud top temperature and CG lightning activity. Similar statistical analyses were performed on the cloud top temperature data set as were performed on the surface temperature data set with the exception that the cloud top data set was normalized due to the extreme range of temperature values.

Poor coefficients of correlation were derived for both negative and positive CG activity exhibiting values averaging 0.250. Standard variation among the sample set was 0.73 for positive activity and 1.49 for the negative activity inferring little deviation among the mean value of one. Furthermore the relatively platykurtic shape of the plotted data set further supports little variation among CG activity in relation to cloud top temperature. No discernable recurring patterns or characteristics were observed between the seven thundersnow events in regards to lightning activity and cloud top temperature. Warmer cloud top temperatures than found by Beckman (1986) are due likely to the broader selection of weaker events than he analyzed.

The results of this analysis may well have been skewed by the limited temporal resolution of the GOES Infrared (IR) imagery resulting in a rather small data set. Future work may involve reanalysis of the NLDN data set by means of more resolute fifteen minute GOES IR data. It is felt that by comparing five minute NLDN data in regards to fifteen minute GOES IR a larger sample set will be obtained resulting in a superior relation between CG activity and cloud top temperature. Furthermore a larger data set of lightning and cloud top characteristics is being compiled.

5. Storm Initiation

The base analysis for this study was performed by gathering hourly and SPECI METAR observations which reported either thundersnow (TSSN) or a combination of Lightning Distant (LTG DSNT) and a report of snow (SN). Although this method of congregation may seem clumsy it has proven to be a dependable first attempt at identifying possible thundersnow events. Through further analyses of these events with respect to NLDN data a more precise storm initiation time can be identified and improved storm duration may also be obtained.

Initiation time of a thundersnow event was determined to be the point at which the first CG strike was recorded in the vicinity of a surface station reporting falling snow and or thundersnow. On average thirty minutes of advanced detection of an event was achieved through this analysis technique over using METAR and or SPECI observations alone. Operationally speaking this level of advanced warning is significant. However, METAR observations are still considered invaluable when dealing with a thundersnow event which involves cloud to cloud and or intra-cloud lightning, which is not available via the NLDN.

Thundersnow event duration ranged from one hour fifteen minutes to nearly six hours. Average duration of the seven investigated thundersnow cases was two hours and forty minutes. These relatively short duration events can greatly affect local transportation and public works since they can deposit large quantities of snow in a short period of time. Identifying thundersnow events prior to event initiation has proven to be a difficult task for the operational forecaster. National Lightning Detection Network data is felt to be a strong tool available to the operational forecaster in identifying thundersnow events enabling the forecaster to promptly warn the public of a thundersnow event.

6. Summary

This study revealed several characteristics of thundersnow events. First nearly all seven of the thundersnow cases studied occurred in vicinity to the rain/snow line, 540 dm thickness line. This observation is substantiated by the fact that the average surface temperature observed during the seven observed events was 30˚F. Overall CG activity peaked just above this average temperature with a value of sixty total CG strikes. An overall rise in CG lightning activity was noted with increasing surface temperature.

Unfortunately little evidence was found relating overall CG activity to cloud top temperature. This could impart be due to sample size of the GOES 12 IR imagery data set. Future investigation of this element should be performed with a larger sample set representing better temporal resolution. Better spatial and temporal resolution may lead to the discovery of cloud top characteristics and CG activity specific to thundersnow events.

Furthermore an average of thirty minutes lead time was obtained by utilizing NLDN lightning data to observe thundersnow event initiation. This additional lead time can be imperative to operational forecasters. NLDN data also exposed the average duration of a thundersnow event to be two hours and forty minutes, with the longest event lasting nearly six hours.

7. Conclusions

Thundersnow events are difficult phenomena to forecast and identify in a timely manner. This study was further defines the surface thermal environment present during initiation of thundersnow events. A relation between surface temperature and CG lightning activity was verified and is felt to be beneficial information for the forecasting of thundersnow events. Unfortunately no correlation or pattern was observed between CG activity and cloud top temperature. Further evaluation of the cloud top environment with a larger data set is required in order for any true relation between CG activity and cloud top temperature to be revealed.

Additional lead time in thundersnow event identification was acquired through utilizing NLDN data in conjunction with METAR reports and satellite imagery. This additional lead time will improve the operational forecaster’s ability to inform the public in a timely manner of an impending thundersnow event improving the safety and security of the public.

References

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